Skydio X2D
AI-powered Autonomous Drone for Organic, Unit-level ISR

By Jeff Jang, Product Marketing Manager

Prologue

The purpose of this white paper is to explain how Skydio autonomous drone solutions are best-suited for Small Unmanned Aircraft System (sUAS) use cases in the Defense customer segment. We propose that the Skydio X2D sUAS, based on the same autonomy platform as Skydio 2, can help bridge current military gaps and further improve the warfighter's capabilities. This white paper was crafted for and by people that understand the requirements of warfighters deployed on the battlefield.

AUTHOR

Jeff Jang

Product Marketing Team member at Skydio. Jeff joined Skydio over a year ago as a Production Manager and led Skydio's transition from prototype building to mass manufacturing. Jeff served over 6 years in the Army as an Infantry Officer with the 101st Airborne Division, during which he deployed to Afghanistan and Iraq. Jeff stays busy in his free-time as a full-time MBA student at the Stanford Graduate School of Business (Class of 2022).

KEY CONTRIBUTORS

Chuck McGraw

Director of Public Sector sales at Skydio. Chuck joins Skydio after 20 years as a Navy SEAL. His career has included eleven combat deployments to multiple theaters of conflict. Chuck has held the positions of Assault Squadron Operations Chief, Basic Training Command Operations Chief, Master Training Specialist, Senior Program Manager and Assault Team Leader.

Sai Williams

Federal Enterprise Account Executive at Skydio. Sai served over 22 years as a SEAL and in the US Army, leading Special Operations teams on numerous deployments around the world. Most recently, he served at the Defense Innovation Unit (DIU) where he worked to speed innovative technology solutions into the hands of service members - both forward deployed and in the United States.

Dylan Hamm

Solutions Engineer at Skydio. Dylan served over 12 years in Special Operations as a SEAL. He helped pioneer use cases, as well as development of Unmanned Aerial Systems (UAS) platforms within his community. He has a unique passion for UAS based on their ability to transform the battlefield, by increasing a unit's organic capacity for situational awareness.

Joe Enke

System Design engineer at Skydio responsible for technology development for defense, commercial, and consumer architectures. 15 years experience in autonomous aerial & ground robotics, imaging, and embedded systems across government and consumer electronic industries at GoPro, Blackberry, and General Dynamics Robotic Systems. He has a masters in electrical & computer engineering from The Johns Hopkins University.

Table of Contents

The Rise of UAS in US Military Operations

Since the beginning of Operation Iraqi Freedom and Operation Enduring Freedom, the use of military Unmanned Aircraft Systems (UAS) has become an irreplaceable tool to gather Intelligence, Surveillance, and Reconnaissance (ISR) for the US Military. UAS allows units to quickly collect, process, and disseminate intel across all echelons within the Area of Operations (AO). Moreover, UAS can provide a tactical advantage to the warfighter through Near Real Time (NRT) situational awareness on the battlefield.

UAS have proven to be a combat multiplier because they:

- **Reduce risk to force:** UAS allows for penetration in high-threat airspaces while significantly mitigating risk to lives of military personnel, including both pilots and ground forces. Furthermore, UAS provides increased situational awareness through synchronization of UAS assets within full-spectrum operations. Military units are capable of gathering NRT information to reduce uncertainty, refine plans, and react to actions on the battlefield, all of which can further reduce risk to human capital.
- **Reduce risk to mission:** UAS increase mission success by reducing the workloads on our military forces. Whereas humans get tired, machines are indefatigable. If designed effectively they can produce reliable and repeatable results, and lower tactical risk for commanders at all levels. The effectiveness of UAS programs is evident in its usage in combat operations. In 2019, General Atomics Predator UAS surpassed 6 million unmanned flight hours, 90% of which were flown in combat operations. In 2016, AAI's Shadow UAS surpassed 1 million unmanned flight hours, 85% of which were flown in combat operations.

Moreover, UAS programs are exponentially faster to adopt and scale than manned aircraft systems, as seen by the cost overruns of Lockheed Martin's F-35 Joint Strike Fighter in the last decade. Another factor to lower costs of UAS programs is lower operating costs. Aviation fuel is expensive - DoD's fuel bill has ranged from as high as $17B in FY2011 to as low as $8B in FY2017. UAS use a fraction of the fuel required to operate manned aircraft. F-35's fuel capacity is 18,300lb with a range of 1200 nautical miles, while MQ-1C Grey Eagle's fuel capacity is 575lbs with a range of 2500 nautical miles.

The Challenges of Fixed-Wing UAS

Current UAS technology employed by the military is dominated by conventional fixed-wing aircraft. The main advantage of fixed-wing UAS is that they are aerodynamically efficient, which allows them to cover long distances and map large areas.

However, the most significant disadvantage of these conventional fixed-wing drones is that they require a large footprint. For example, large UAS such as **General Atomics Grey Eagle** (successor to the Predator) require a runway and engine to take-off and land. Even smaller aircraft such as **AAI's Shadow** and **Boeing's ScanEagle** require a large open space and a pneumatic launcher. This makes fixed-wing drones largely impractical to employ within tactical elements on the forward lines.

General Atomics MQ-1C Grey Eagle
(Successor to MQ-1 Predator)

Wingspan:	56ft
Length:	28ft
Fuel Capacity:	575 lb
Method of Takeoff:	165HP engine
Cost:	$167M per aircraft

AAI RQ-7B Shadow

Wingspan:	20ft 4in
Length:	14ft
Fuel Capacity:	35.2kg
Method of Takeoff:	Launcher
Cost:	$750K per aircraft

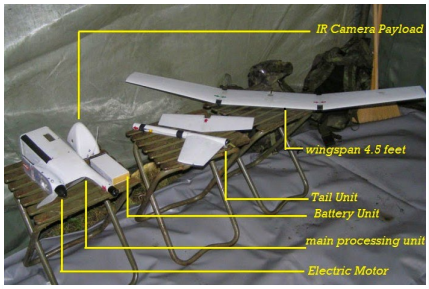
Boeing Insitu ScanEagle

Wingspan:	10ft 2in
Length:	4ft 6in
Fuel Capacity:	4.3kg
Method of Takeoff:	Launcher
Cost:	$3.2M per system

DoD has tried to close this gap in capability with small Unmanned Aircraft System (sUAS) drones. The FAA's definition of sUAS drones are systems that weigh less than 55 lbs. The Defense Innovation Unit's (DIU) Blue sUAS program further specifies for drones to have a take-off weight of less than 3 lbs.

In theory, portable drones with a smaller and lighter airframe require a much smaller footprint and therefore ground forces on the front lines could launch them for rapid battlefield reconnaissance and intelligence gathering. What would otherwise take a scout team a day to accomplish, can be done within hours with the use of drones.

Up until recently, DoD's sUAS solution has been dominated by fixed-wing drones, specifically AeroVironment's RQ-11B Raven and RQ-20 Puma. However, the problem with these legacy solutions is that they fall short in several areas to make them optimal systems.

Problems	Fixed-Wing sUAS	
Long assembly time		There are multiple parts that need to be assembled prior to use, such as the sensor payload, fuselage, tail unit, elevator, wings, and battery. These systems are not "out-of-the-box" solutions.
Lack of portability		Both Raven and Puma require multiple large Pelican cases to transport - despite how it is advertised, they do not really provide a "rucksack portable" solution
Operating complexity	The Army's Raven/Puma sUAS training course is 6-8 weeks long. Soldiers graduate with basic knowledge of how to operate both systems, but require continued training to maintain confidence and competency.	
Lack of reliability	 	Hand-launching isn't always reliable, whether due to user error or uncontrollable factors such as wind. Belly-landing can cause damage to aircraft components and require additional time and resources to maintain/fix. Furthermore, the launch and recovery process for Ravens and Pumas means that soldiers must expose themselves outside of their cover and concealment positions.
Difficulty capture detailed ISR	Fixed-wing UAS cannot hover - they orbit instead. Especially at lower altitudes (<500ft), it is difficult to remain fixed on a target, making fix-wing sUAS unsuitable for quality aerial photography and videography, which is highly relevant to ISR for DoD purposes.	
High cost	Raven - $260K per system (includes 4x UAS, 2x GCS, and spare parts) Puma - $250K per system (includes 3x UAS, 2x GCS, and spare parts)	

For these reasons, conventional ground force maneuver elements, as well as Special Operations teams avoid using their fixed-wing drones despite having full control over the deployment of these organic assets. Yet, DoD continues to invest in these largely unused legacy solutions.

Then what solution can be offered to service members to actually utilize the full potential of sUAS platforms? The reluctance to use legacy sUAS solutions isn't due to a lack of demand for an organic, unit-level ISR platform. ISR assets are normally controlled at the strategic and operational levels of planning. At the tactical level of planning however, ISR assets must be requested and yet can be denied due to competing priorities. An effective organic, unit-level ISR platform can fundamentally change how wars are fought, because it would allow more autonomy at the tactical level.

The Need For Organic, Unit-level ISR to Ensure Mission Success

For sUAS to succeed, technology must be developed in a way that is not only functional, but also easy for any soldier to operate and employ on the battlefield, without worrying about losing or crashing the drone. For most soldiers piloting a drone is not their primary skillset, so sUAS solutions designed to require an "expert pilot" are not scalable and bound to fail.

Moreover, sUAS platforms should be designed with consideration of the increasing battlefield combat load of the average soldier. Based on studies, combat loads have increased from a range of 53-81 pounds in 2003 to a range of 96-140 pounds in 2017. This weight burden means that soldiers will be highly economical when deciding what to carry. If a soldier does not view a piece of equipment as a net positive to mission success, it will likely be left behind. So when designing military sUAS platforms, factors such as being rugged, reliable, compact, lightweight, and portable must not be compromised.

Furthermore, for superior ISR capabilities, sUAS platforms must have state-of-the-art sensors combined with user-friendly software to operate in multiple conditions and environments. They should be designed to be able to:

1. **Find** the target/objective
2. **Fix** the target/objective in space and time
3. Assist in **Finishing** the mission
4. **Exploit** the objective site for intelligence
5. Capture actionable imagery/video to **Analyze**
6. Rapidly **Disseminate** the intelligence to relevant stakeholders by owning the raw data

Finally, security is becoming an increasingly critical requirement. Concerns of counter-UAS technology and supply chain country of origin threats have become national security risks. If enemy forces successfully capture a friendly UAS, they may be able to exploit information and develop counter-measures. Developing a platform that prevents the enemy from downloading data is more important now than ever.

Skydio X2D: Unmatched Autonomy Meets Military-Grade Performance

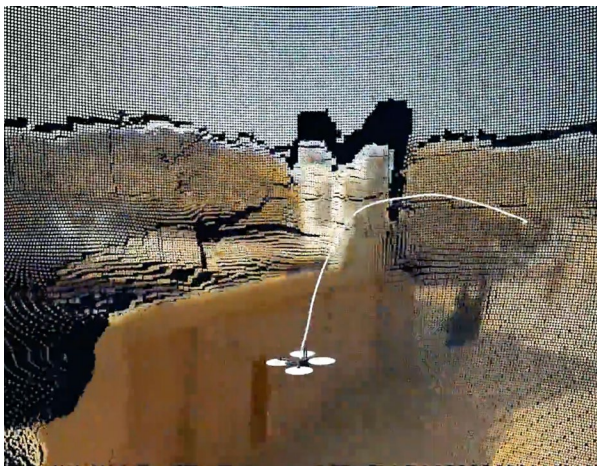
Enter Skydio X2D, the answer to the warfighter's need for a solution to fill the capability gap of legacy sUAS drones. The X2D system delivers a trustworthy NDAA compliant solution designed and manufactured in the USA, and built to exceed the requirements of the U.S. Army Short Range Reconnaissance (SRR) program of record, making it the ultimate solution for military and defense to perform reconnaissance, search and rescue, and security patrol missions.

Let's explore the key characteristics of the system that sets it apart from any other option available in the market today.

AI-Powered Autonomy for Reduced Cognitive Overload

Embedded into every X2D, **Skydio Autonomy™ delivers the simplest and safest flight experience,** which lets the soldier focus on the mission at hand, instead of the complexity of piloting the drone. Skydio Autonomy has ushered a new generation of drone intelligence, using breakthroughs in artificial intelligence, computer vision, and robotics to fly autonomously through the most demanding environments. The following are core autonomy capabilities, which should be considered prerequisites to build the kind of next-gen drone fleet necessary to provide a true tactical edge:

- **Real-time 3D Mapping:** The drone uses six 4K 200 degree navigational cameras to achieve depth perception and to maintain a 3D map of its surroundings in real-time.
- **Object and Scene Recognition:** 9 deep learning networks enable the drone to recognize objects and predict how they will persist in the environment.
- **Motion Planning:** The drone plots a safe path through its environment to fulfill the pilot's commands or reach pre-planned locations.
- **360° Obstacle Avoidance:** The drone uses navigation cameras and real-time 3D mapping to detect static obstacles and plot intelligent paths around them.



Traditional drone solutions that are still based on hardware specifications will use words like "vision sensors" and "omnidirectional obstacle avoidance" to claim that they are capable of autonomous flight, but the reality is that while these drones may react to a few obstacles, they do not have 360° sensor coverage and therefore a comprehensive understanding of their surroundings required to provide true flight autonomy assistance to the pilot.

The outcome of true AI-driven autonomy as delivered by Skydio is reduced cognitive load on the soldier operating the drone, which fundamentally shortens sensor to soldier lag time. Autonomy alleviates major pain points relative to the status quo of fixed-wing sUAS:

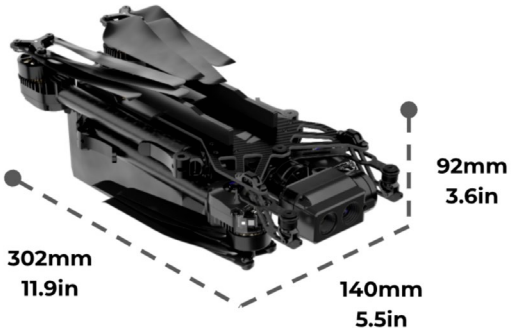
1. **Reducing risk to force** - seamless integration between tech and operator that reduces cognitive load
2. **Reducing risk to mission** - mitigate risk of crashes that can expose the position of the unit on the battleground
3. **Ease of operations** - Skydio Autonomy reduces the skill barrier required to competently operate a drone and allows any Soldier to confidently fly with the skills of an expert pilot

Autonomy matters even more when you add the element of operating in an unknown or austere environment.

Ruggedized and Portable for Organic, Unit-Level Deployment

The X2D aircraft features a ruggedized airframe, built of magnesium and carbon fiber composite material that provides maximum flight stability optimized for autonomy, as well as durability against the elements. The Skydio Enterprise Controller, paired with X2D for ground control operation, is built with high-impact plastic that will last in tough, austere environments, while the protective cover protects the display, joysticks and buttons, as well as the antenna, which is actually built into the cover. This emphasis on durability and ruggedness will allow squads on the ground to carry the system to any mission with confidence.

From a portability standpoint, X2D is designed with foldable antennae and foldable arms to enable "pack and go" transportation inside the soldier's rucksack, as well as a quick and easy system deployment that can be fully completed in under 90 seconds. The Enterprise Controller is highly functional and ergonomic, by giving it a bright built-in touchscreen, large glove-compatible controls, contoured design, and rubber grips.



The powerful combination of portability and ruggedness is a convincing reason for any ground force unit to use X2D as their organic ISR asset, further reducing the need for external asset requests.

Equipped to Operate in Multiple Conditions and Environments

X2D can operate and capture ISR in multiple conditions. For high-fidelity image capture, the aircraft carries a front-mounted gimbal with a dual sensor payload composed of a 4K HDR color camera with 16x zoom and a FLIR® Boson 320x256 thermal imager with 8x zoom.

When flying during daylight, the Skydio Autonomy™ engine relies on the **Skydio Visual Navigator™, a one-of-a-kind vision-based navigation system** that depends on six 4K 200 degree navigation cameras aboard the drone, instead of GPS or magnetometer calibration. Vision provides far superior perception than manual GPS-based systems, and allows the aircraft to operate in GPS-contested environments, such as indoor, overhung, and even through electromagnetic interference when flying near metallic structures.

When the mission is successfully completed, **Visual Return-to-Home (RTH)** is a unique, software-enabled capability that allows X2D to get back to base through those same GPS-denied environments by navigating home using the computer vision system.

For night-time operations, the drone is equipped with **GPS Night Flight** using on-board GPS and magnetometer (notice obstacle avoidance is disabled when flying in this mode). Combining GPS navigation, thermal sensing and strobe lighting in both IR and visible wavelengths to avoid collisions from friendly aircraft in the area, the drone is capable of safely operating in the dark.

AI-Pilot Assistance for Maximum Efficiency and Situational Awareness

Skydio Autonomy is equipped with powerful pilot-assist capabilities that make every flight safer and more efficient for the operator on the ground.

360 Superzoom™ for maximum situational awareness. 360 Superzoom blends the drone's seven on-board cameras to let the pilot see in all directions while flying, and provides up to 16x digital zoom with high quality video resolution and electronic image stabilization to reliably lock on the target.

Close Proximity Obstacle Avoidance for detailed inspections or tactical situational awareness in dense environments. The autonomy engine can be tuned to enable it to safely fly in close proximity to obstacles (.5 meters), which allows the operator to fly confidently in tight spaces and to achieve success faster.

180° Vertical View to capture overhung images. The gimbal can look straight up overhead of the drone. Combined with obstacle avoidance, this allows the operator to squarely focus on overhead inspection targets, instead of dedicating cognitive capacity to flying around obstacles.

Point of Interest (POI) Orbit for increased situational awareness and security patrol. The drone can fly up and outward while rotating around a point on a map defined by the user. Combined with Subject Recognition and Obstacle Avoidance, the operator can orbit a point of interest with confidence, without the worry of the drone hitting an obstacle.

3D Scan™ for complex inspections and scene reconstruction. The ability to utilize organic 3D reconstruction in military operations is a game changer. Have you ever wanted to capture a 3D map of your AO in real time to develop a detailed Common Operating Picture (COP) instead of relying on outdated satellite imagery? The combination of the aircraft's EO/IR sensor and 3D reconstruction data can be piped into a COP to build out a holistic, data driven understanding of the battlefield not yet obtainable until the arrival of the X2D.

With this set of capabilities further augmenting the reach of the drone, X2D re-defines how intelligence data is collected, analyzed, and utilized. Instead of worrying about flying, or rather **not crashing**, Soldiers can truly focus on the information collection mission that they have been assigned to support.

Secure and Trustworthy Blue sUAS, Designed and Built in the USA

DoD agencies need to handle sensitive data in trustworthy ways. Skydio X2D is designed to deliver ironclad, end-to-end protection. From a cybersecurity standpoint, the entire system is protected from data exfiltration or compromise of command-and-control by nefarious actors:

- Wireless connection encryption and authentication (AES-256 for 1.8GHz, AES-128 for 5GHz)
- Encrypted and signed software updates
- Key provisioning burned-in at time of manufacture that provides root of trust and primitive for cryptographic operations
- Media card encryption via physical FIPS 140-2 hardware security key
- Enterprise Controller has an encrypted hard drive with password protection, trusted boot with anti-rollback. DISA approved for DoD use.

Ultimately though, the most important way to gain the customer's trust regarding the integrity and security of the system is to prove that the manufacturer itself and the legal framework in which it operates can be trusted. Skydio takes pride in designing, assembling and supporting drones from our headquarters in the United States. Our products meet the highest levels of supply chain security demanded by the US government, including compliance with National Defense Authorization Act (NDAA) and American Security Drone Act (ASDA). This means that when Soldiers take X2D on a mission, they can have confidence that they have full control over both their drone and their data.

For these reasons, Skydio X2D was selected as a trusted drone platform for the Department of Defense and Federal Government as part of DIU's Blue sUAS Program, making it available for purchase on the GSA schedule.

Skydio X2D, a True Force Multiplier

The X2D is capable of providing "over the hill" or "around the corner" type of reconnaissance, surveillance, and target acquisition, making it the only organic, unit-level ISR asset you will need. Furthermore, as a VTOL (Vertical Take Off and Landing) sUAS drone, it allows for superior control and positioning in space-constrained areas, since VTOL drones are the optimal choice for tactical maneuver units.

Here's a glimpse of how X2D can be a part of every aspect of the mission lifecycle:

ISR Mission Support	Key Skydio features	Positive Impact on the Mission
Intelligence	4K HDR sensor w/ 16x zoom, 35 min flight time	X2D allows troops to easily and efficiently gather real time combat information about terrain, friendly unit actions, and the disposition of possible enemy elements at an incredible resolution of up to 4K and loiter of up to 35 mins per battery charge.
Surveillance	FLIR® Boson 320x256 LWIR Thermal imager	X2D gives you the power of a TWS (Thermal Weapon Sight) in a compact drone. The FLIR Thermal imager, coupled with Skydio's mechanical and digital stabilization allow ground forces to obtain high fidelity thermal imagery, plus the ability for 8x digital zoom while maintaining clear PID.
Reconnaissance	GPS Night Flight Strobe Lighting	Operating UAS in the middle of the night is challenging and risky due to significantly reduced sensory input. With X2D, troops can bring low signature, organic ISR capabilities to the ground force. This means more available sensors for leadership to dedicate across the operational area, without taking eyes off critical locations.
Target Acquisition	Object and Scene Detection	Target acquisition, detection, and recognition is now made easy using autonomy-based Object and Subject Recognition, which allows X2D to follow desired targets with full collision avoidance and motion prediction.

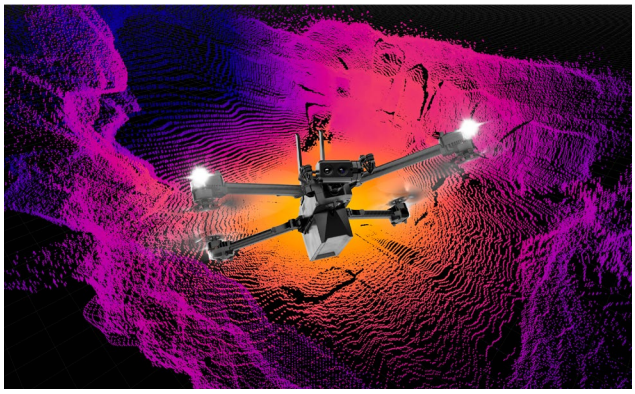
ISR Mission Support	Key Skydio features	Positive Impact on the Mission
Situational Awareness	360 Superzoom	Provides Ground Force Commanders with C2 (Command and Control) superiority and the capability of a full omnidirectional view that helps spot obstacles, targets, and activity with up to 16x digital zoom, while hovering in place.
Security & Movement Support	Close Proximity Obstacle Avoidance + 180 Vertical View	Provides the maneuvering element with the organic capabilities of overwatch security, area security, and real time oversight of enemy ingress/egress routes.
Incident Response (post-IED, VBIED blast, crashes, etc.)	3D Scan	3D Scan can be used as an integral part of a unit's Incident Response analysis. Current disadvantages are that it's slow, often inadequate, and resource intensive. Being able to capture 3D imagery intelligence to conduct timely and accurate post blast analysis, while vastly decreasing the risk to force is an incredibly valuable asset on the battlefield.
Gathering and sharing data	Immediate video access	Directly download video and photos from encrypted SD cards, which allows for immediate analysis to provide timely debriefs and answers for CCIRs (Commander's Critical Information Requirements).

Components of the Skydio Solution for Defense

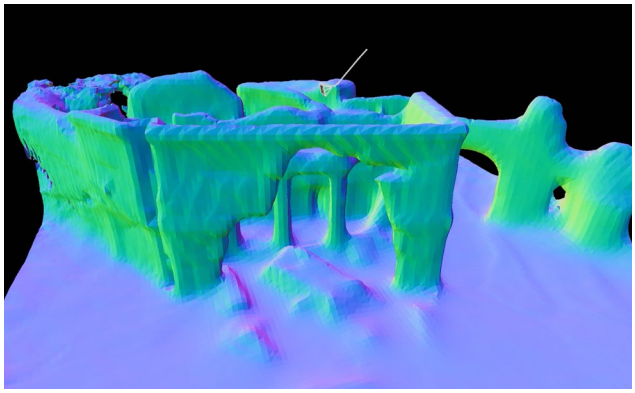
Now that we have explored how Skydio technology can address pain points and challenges of the sUAS status quo while meeting key operating requirements, here's a concise summary of the components that you need to procure to take advantage of the X2D system.

Skydio X2D. Pairs the breakthrough Skydio Autonomy™ engine with a ruggedized airframe that features a dual color/thermal sensor, long-range operations with wireless radio configurations in both 5GHz or the reserved 1.8 GHz channel, and extended battery life for up to 35 minute loiter. Core autonomy capabilities of the drone previously described in this paper include **360° Obstacle Avoidance**, **Object and Scene Recognition**, and **Skydio Visual Navigator**.

Skydio Enterprise Controller. Ground control for X2D is enabled via the Skydio Enterprise Controller, which was designed from the ground up for pilots and soldiers with demanding operating requirements. Ground control software is natively delivered via the **Skydio Enterprise App**, with optionality to operate using the **Skydio QGroundControl App**.



Skydio Autonomy Enterprise Foundation. An optional software package that augments the core autonomy engine. It's designed to assist the pilot through software capabilities that enhance situational awareness and facilitate flight in obstacle-dense environments. Key features of this package previously presented in this paper include **360 Superzoom**, **Close Proximity Obstacle Avoidance**, **180 Vertical View**, **Orbit POI and Visual Return to Home**.



Skydio 3D Scan™. The first-of-its-kind general-purpose digital scan software for inspections of complex structures and locations, 3D Scan is powered by a new real-time visual 3D reconstruction engine. 3D Scan fully automates the scanning process by autonomously imaging all surfaces at a precise overlap and GSD, ensuring that the imagery has no gaps, and that is optimized to efficient photogrammetry.

Why Autonomy Matters for DoD

The Information Age has changed the way Soldiers see, think, communicate, and act, as the military modernizes through adoption of digital innovations. Artificial Intelligence and autonomy are giving rise to the next race for technological superiority and will become the new driving factor of the military's digital transformation.

All existing military UAS solutions currently lack autonomy. This means that pilots need to go through extensive training and certification programs as a result of the complexity of these systems. Moreover, drones are costly to procure, maintain, and replace. The use of legacy technology leads to a greater risk of mission failure and the risk of crashes remains the number one concern among military units and soldiers.

With powerful, modern hardware and the Skydio Autonomy engine, the Skydio X2D is a state-of-the-art ISR collection asset, completely changing how intelligence can be gathered and used on and off the battlefield. X2D can help the military flatten the ISR planning and synchronization process. The Forward Line of Troops will have full control of real-time intelligence gathering before, during, and after the execution of any mission or operation. And ultimately it will help deconflict theater level ISR asset management and decentralize how ISR is collected.

All of this is accomplished by using autonomy to augment human skills rather than replace them. The ethical Human-in-the-loop is still at the core of all battlefield considerations and Skydio Autonomy requires trained and professional Soldiers to operate and maintain the X2D.

Skydio's autonomous drone solutions provide a tactical edge to our military forces by enabling the easiest and safest flight experience, so that Soldiers can focus on the mission and the fight, instead of wasting cognitive load on the flight. The Skydio X2D will better inform our forces, leading to increased safety and ultimately more positive tactical outcomes.

Better Soldiers + Better Intelligence = Battlefield Superiority